

TITLE OF THE INVENTION
A FAST SIGNAL DETECTION PROCESS

5 CROSS REFERENCE TO RELATED PATENTS

BACKGROUND OF THE INVENTION

10 TECHNICAL FIELD OF THE INVENTION

This invention relates generally to wireless communications and more particularly to radio receivers used within such wireless communication systems.

DESCRIPTION OF RELATED ART

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Wireless communication systems are known to include a plurality of wireless communication devices that communicate over wireless communication channels, which are supported by wireless communication infrastructure equipment (e.g., base stations, access points, system controllers, wide area network interfaces, local area network
20 interfaces, et cetera). Each wireless communication device, which may be a radio, cellular telephone, station coupled to a personal digital assistant, personal computer, laptop, et cetera, includes a radio transmitter and a radio receiver. The radio transmitter includes a baseband processor, one or more intermediate frequency stages, filters, and a power amplifier coupled to an antenna. The baseband processor encodes and/or
25 modulates, in accordance with a wireless communication standard such as IEEE 802.11a, IEEE802.11b, Bluetooth, Global System for Mobile communications (GSM), Advanced Mobile Phone Service (AMPS), et cetera, to produce baseband signals. The one or more intermediate frequency stages mix the baseband signals with one or more local oscillations to produce a radio frequency signal. The filter filters the radio frequency
30 signal to remove unwanted frequency components and the power amplifier amplifies the filtered radio frequency signal prior to transmission via the antenna.

A radio receiver is known to include a low noise amplifier, one or more intermediate frequency stages, filters, analog to digital converters, and a receiver baseband processor. The low noise amplifier amplifies radio frequency (RF) signals received via an antenna and provides the amplified RF signals to the one or more intermediate frequency stages. The one or more intermediate frequency stages mixes the amplified RF signal with one or more local oscillations to produce a receive baseband signal. The analog to digital converters convert the received baseband signal into a digital baseband signals. The receiver baseband processor, in accordance with a particular wireless communication standard, decodes and/or demodulates the digital baseband signals to recapture data therefrom.

As is further known, the magnitude of an RF signal received by the receiver may vary by 80dB or more. As such, the receiver includes an automatic gain control module to control the gain of the low noise amplifier, the intermediate frequency stage or stages, the filters and/or the analog-to-digital converters to keep the magnitude of the received signal at levels within the dynamic operating range of the circuitry comprising the receiver.

Prior to receiving a valid RF signal, the automatic gain control sets the gain of the receiver at a level to detect the presence of the weakest signal allowed by the governing standard. As such, the gain of the receiver, which includes multiple gain stages, is set very high. With the gain of the receiver set in this manner, the receiver measures the signal strength of what it is receiving and compares it to a threshold. In the absence of a valid signal, the receiver is receiving noise. To distinguish between noise and a weak valid signal, the automatic gain control sets the gain of the receiver such that the signal strength of the noise is a fixed power level below a potentially valid signal threshold (e.g., 10dB below the threshold).

An issue with this signal detection approach is that, over time, the signal strength of the noise varies due to environmental changes in which the receiver is located. If these

variations are not accounted for, valid signals may be missed (i.e., the sensitivity of the receiver is reduced) or the receiver will produce false/positive signal detections (i.e., the signal level of the noise will approach the threshold). The former results when the signal strength of the noise decreases and the later occurs when the signal strength of the noise increases.

To reduce the false/positive signal detects and the decreased receiver sensitivity, many receivers have the automatic gain control adjust the gain stages of the receiver to keep the signal strength of the noise at the predetermined value below the threshold. An issue with this approach is that the gain increments/decrements are finite and that to achieve the desired adjusted gain of the multiple gain stages; several of the gain stages are adjusted. If the gain stages are adjusted at the same time, a significant fluctuation in the signal level may occur, causing a false positive signal detect. To avoid this, the gain stages are adjusted sequentially, which requires a fair amount of time. Thus, if a valid but weak signal is received while the gain is being adjusted, the signal may be missed, especially for signals having a short training sequence such as those prescribed in the IEEE 802.11 standard.

Therefore, a need exists for a method and apparatus for quickly detecting the presence of a valid signal and improving receiver sensitivity in comparison to the above.

BRIEF SUMMARY OF THE INVENTION

The low power valid signal detection process of the present invention substantially meets these needs and others. In one embodiment, a valid signal may be detected by initializing gain settings of the receiver section. The processing then continues by measuring received signal strength of a signal received by the receiver section to produce a 1st received signal strength indication (RSSI). The processing continues by adjusting the gain setting of the receiver section such that the 1st received signal strength indication is a predetermined offset less than a signal strength threshold. The process then continues by measuring the received signal strength of the gain adjusted representation of the signal to produce a 2nd received signal strength indication. The

processing continues by appending a 2nd offset to the 2nd received signal strength value to produce an adjusted received signal strength indication value when the 2nd received signal strength value drifts from the signal strength threshold less the predetermined offset. This adjustment substantially maintains the signal strength threshold less the adjusted RSSI value to be substantially equal to the predetermined offset. The processing continues by measuring the received signal strength of received signals and appending the offset until a possible valid signal is detected. When the possible valid signal is detected (e.g., the signal strength exceeds the threshold or a cross correlation indicates a possible signal), the gain of the receiver is adjusted based on its dynamic range. With such a method, the gain of the receiver is set once until a potentially valid signal is received. Thus, by appending an offset to the received signal strength indication, the gain of the receiver does not need to be changed, which improves the receiver's sensitivity and reduces latencies that cause the receiver to miss valid signals.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Figure 1 is a schematic block diagram of a radio receiver in accordance with the present invention;

Figure 2 is a graph of the signal strength of a signal received via the receiver of Figure 1 in comparison with a signal strength indication threshold;

Figure 3 is a graph illustrating the signal strength of a possibly valid signal as processed by the receiver of Figure 1;

Figure 4 is a graph of processing a possibly valid signal by the receiver of Figure 1;

Figure 5 is a logic diagram of a method for detecting the presence of a valid signal in accordance with the present invention;

Figure 6 is a logic diagram of an alternate method for detecting the presence of a valid signal in accordance with the present invention; and

Figure 7 is a logic diagram of yet another method for detecting the presence of a valid signal in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a schematic block diagram of a radio receiver 10 that includes low noise amplifier 12 operably coupled to an antenna, a down-conversion module 14, analog-to-digital converter (ADC) 16, two multipliers 20 and 22, a complex low pass filter 26, a demodulation module 28, a data detection module 30, a 1st received signal strength indication (RSSI) module 32, a 2nd RSSI module 34 and an automatic gain control (AGC) module 36. In operation, the low noise amplifier 12 amplifies a radio frequency (RF) signal 44, which is received via the antenna, to produce an amplified RF signal 46. The down conversion module 14 converts the amplified RF signal 46 into an intermediate frequency signal 48. The down conversion module 14 produces the IF signal 48 by mixing the amplified RF signal 46 with a local oscillation.

The analog-to-digital converter 16 converts the intermediate frequency signal 48 into digital signals. As shown, the frequency spectrum of the IF signal 48 is centered about the intermediate frequency and may have a bandwidth of approximately 80 megahertz for IEEE 802.11 applications. The mixers 20 and 22 mix the digital IF signal 48, respectively, with an in-phase and quadrature component of a local oscillation (LO_{IF}) to produce an in-phase (I) component and a quadrature (Q) component. The complex low pass filter 26 filters the I and Q components to produce a complex baseband signal 49. The complex baseband signal 49 may have a frequency spectrum centered about 0 hertz and may have a bandwidth of approximately 20 megahertz for IEEE 802.11 applications.

The data detection module 30 is operably coupled to determine when the complex baseband signal 49 is a valid signal. When the complex baseband signal 49 is a valid

signal, the data detection module generates a valid signal indication 50 that is provided to the demodulation module 28. The demodulation module 28, in response to the valid signal indication 50, recaptures data 52 from the complex baseband signal 49.

5 The low noise amplifier 12, down-conversion module 14, which includes mixers, and the analog-to-digital converter 16 have a nominal dynamic range of operation that, if exceeded, clips the processing of the received RF signal 44. As such, the automatic gain control module 36, based on signal strength indications RSSI 54 and/or RSSI 56, controls the gain of the low noise amplifier 12, the down-conversion module 14 and/or the analog-
10 to-digital converter 16 via LNA gain signal 42, mixer gain signal 40, and/or ADC gain signal 38. As such, when a valid baseband signal 49 is being received, the AGC module 36 generates gain control signals 38-42 to ensure that the processing of the RF signal falls within the nominal dynamic operating range of the LNA 12, the down-conversion module 14, and the analog-to-digital converter 16.

15 Prior to a valid baseband signal 49 being received, the AGC module 36 sets the gain of the LNA 12, the down-conversion module 14, and/or the analog-to-digital converter 16 to detect a weak, but valid incoming RF signal 44. The AGC module 36 sets the gain of these components once such that the noise level is a predetermined signal
20 strength level below a possible valid signal strength. Thus, as the noise level and/or the gain of the receiver drift over time, the receiver 10 accounts for the drift, as further described with reference to Figures 2-7, without having to change of the gain of the receiver. . As such, the radio receiver 10 of Figure 1, quickly and accurately detects the presence of an incoming valid signal since the gains of the receiver are not continually
25 updated, which also improves the receiver's sensitivity since the threshold between a valid signal trigger-point and the measured signal strength of noise is maintained.

 Figure 2 illustrates a graph of the receiver 10 of Figure 1 receiving noise and the AGC module 36 adjusting the sensitivity of the receiver prior to a valid signal being
30 received. As shown, the graph plots the magnitude, in decibels, of the digital IF signal 48 versus time. An initial measurement is made via the 1st RSSI module 32 to produce the

1st RSSI value 54. Based on this value, the AGC module 36 increases the gain (or decreasing as the case may be) of the LNA 12, the down-conversion module 14, and/or the analog-to-digital converter 16 such that the adjusted signal strength of the digital IF signal 48 is a predetermined offset less than the RSSI threshold. The predetermined offset may be, for example, 10dB. The gain of the LNA, the down-conversion module, and the analog-to-digital converter, will remain at this level until a valid signal is indicated.

As further shown in Figure 2, as time passes, the signal strength of the digital IF signal 48 drifts. Via the 1st RSSI signal 54 and/or the 2nd RSSI signal 56, which is produced by the 2nd RSSI module 34, the AGC module 36 mathematically accounts for the drift such that, from a mathematical prospective, the signal strength of the digital IF signal 48 is maintained at the RSSI threshold less the offset. This may be done by determining the amount of drift and appending the drift, as a 2nd offset, to the 2nd RSSI value, which may correspond to the 1st or 2nd RSSI signal, of the digital IF signal 48 to produce an adjusted RSSI value. For example, if the RSSI threshold is at -80dB, the offset is -10dB, then the digital IF signal 48 should have a signal strength of -90dB after the initial adjustment of the gains of the LNA, down-conversion module and the ADC. If the signal strength of the digital IF signal 48 drifts by -3dB to -93 dB, then the magnitude of the -3dB drift (i.e., 3 dB) is appended to the digital IF signal 48 such that the effective digital IF signal strength is -90dB.

As time continues, the drift may increase the signal strength of the digital IF signal 48 which may indicate that a low power signal is being received or drift is occurring that would require mathematical compensation as previously described.

Figure 3 illustrates a graph of when a valid signal is being received. As shown, the gain of the LNA, the down-conversion module, and the analog-to-digital converter are initially set such that the signal strength of the digital IF signal 48 is the offset value below the RSSI threshold. When a valid signal is received, the signal strength of the digital IF signal 48 increases dramatically exceeding the RSSI threshold and may exceed

the desired power level. At this point, the AGC module 36 sets the gains of the LNA 12, the down-conversion module 14, and/or the analog-to-digital converter 16 to nominal gain settings. For example, if the signal strength of a received signal can vary from -20dB to -80dB, the nominal settings would correspond to a -50dB signal.

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Once the receiver has settled with respect to the nominal gain settings, the signal strength is again measured via the 2nd RSSI module 34. Based on this measurement, the AGC module 36 adjusts the gains of the LNA 12, the down-conversion module 14, and/or the analog-to-digital converters 16 and 18 such that the power level of the received digital IF signal 48 is at a desired power level. As one of average skill in the art will appreciate, the magnitude of the digital IF signal 48 may not exceed the desired power level, but exceed the RSSI threshold, as such, the nominal gains would still be set by the AGC module 36 and subsequently increased such that the desired power level is established.

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Figure 4 is a graph representing the receiver 10 receiving a weak, but valid, RF signal 44. As shown, the AGC module 36 initially adjusts the gain of the LNA, the down-conversion module 14, and/or the analog-to-digital converters 16 and 18 such that the signal strength of the digital IF signal is at a level that is the RSSI threshold less the offset. At a later point and time, a correlation process within the data detection module 30 indicates that the RF signal 44 may be a valid signal, which commences as a training sequence of the signal. At this point, the 2nd RSSI module 34 measures the signal strength of the baseband signal, which is used to adjust the gain settings of the LNA, the down-conversion module, and/or the analog-to-digital converters such that the signal is at the desired power level.

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Figure 5 is a logic diagram of a method for detecting the presence of a valid signal. The process begins at Step 60 where gain settings of a receiver section (the LNA, the down-conversion module, and/or the analog-to-digital converters) is initialized. This was described with reference to Figures 2-4. The process then proceeds to Step 62 where the received signal strength indication of a signal is measured to produce a 1st RSSI

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value. The process then proceeds to Step 64 where the gain of the receiver section is adjusted such that the 1st RSSI value is a predetermined offset less than an RSSI threshold. This was also illustrated and discussed with reference to Figures 2-4.

5 The process then proceeds to Step 66 where the RSSI of the gain adjusted representation of the signal is measured to produce a 2nd RSSI value, which may be done by the 1st or 2nd RSSI module. The process then proceeds to Step 68 where determination is made as to whether the 2nd RSSI value drifts from the signal strength threshold (e.g., the RSSI threshold) less the predetermined offset. If so, the process proceeds to Step 70
10 where the drift is measured and appended to the 2nd RSSI value as a 2nd offset to compensate for the drifting. This mathematical adjustment maintains the adjusted RSSI value at a value corresponding to the signal strength threshold less the predetermined offset without having to adjust the actual gains of the LNA, the down-conversion module, and/or the ADCs. The process then proceeds to Step 72 where determination is made as
15 to whether a possible signal is detected. If not, the process repeats at Step 66. If so, the process proceeds to Step 74 where the gains of the receiver section are adjusted based on the dynamic range of the receiver section (e.g., sent to a nominal value within the dynamic range).

20 Figure 6 is a logic diagram of an alternate method for detecting presence of a valid signal in an RF receiver. The process begins at Step 80 where the gain settings of the receiver section are initialized. The process then proceeds to Step 82 where the received signal strength indication of the signal received by the receiver section is measured to produce a 1st RSSI value. The process then proceeds to Step 84 where the
25 gain settings of the receiver section are adjusted such that the 1st RSSI value is a predetermined offset less than a signal strength threshold.

 The process then proceeds to Step 86 where the RSSI of the gain adjusted representation of the signal is measured to produce a 2nd RSSI value, which may be done
30 via the 1st or 2nd RSSI module. The RSSI value may be mathematically adjusted over time prior to the reception of a possible valid signal as described with reference to

Figures 2-4. The process proceeds to Step 88 and 90. At Step 88, the 2nd RSSI value is compared with a signal strength threshold. At Step 90, a correlation is performed on the gain adjusted representation of the signal with a predetermined signal.

5 The process then proceeds to Step 92 where the determination is made as to whether the comparison or the correlation indicates a possible valid signal. If not, the process reverts back to Step 86 and continues in a loop of Steps 86-92 until a possible valid signal is indicated. Once a possible valid signal is indicated, the process proceeds to Step 94 where the gain settings of the receiver section are adjusted based on the
10 dynamic range of the receiver to operate at a desired power level.

 Figure 7 is a logic diagram of another method for detecting the presence of a valid signal. The process begins at Step 100 where a 1st RSSI value of an in-band spectrum of an incoming signal is determined. This may correspond to measuring the signal strength
15 of the complex baseband signal. The process then proceeds to Step 102 where the gain settings of the receiver section are adjusted based on the 1st RSSI value to a pre-signal detect level to produce an adjusted gain setting. The process then proceeds to Step 104 where an incoming signal is amplified in accordance with the adjusted gain setting of the receiver section to produce an amplified incoming signal.

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 The process then proceeds to Step 106 where a 2nd RSSI value is determined for wide band spectrum of the amplified incoming signal, this may correspond to the IF signal. The process then proceeds to Step 108 and 110. At Step 108, the 2nd RSSI value is compared with a signal strength threshold. At Step 110, a correlation is performed on
25 the gain adjusted representation of the signal with a predetermined signal.

 The process then proceeds to Step 112 where a determination is made as to whether the comparison and/or the correlation indicates a possible valid signal. If not, the process reverts to Step 106 and remains in a loop of Steps 106-112 until a possible
30 signal is indicated. Once a possible signal is indicated, the process proceeds to Step 114

where the gain settings of the receiver section are adjusted based on the dynamic range of the receiver section.

As one of average skill in the art will appreciate, the term “substantially” or “approximately”, as may be used herein, provides an industry-accepted tolerance to its corresponding term. Such an industry-accepted tolerance ranges from less than one percent to twenty percent and corresponds to, but is not limited to, component values, integrated circuit process variations, temperature variations, rise and fall times, and/or thermal noise. As one of average skill in the art will further appreciate, the term “operably coupled”, as may be used herein, includes direct coupling and indirect coupling via another component, element, circuit, or module where, for indirect coupling, the intervening component, element, circuit, or module does not modify the information of a signal but may adjust its current level, voltage level, and/or power level. As one of average skill in the art will also appreciate, inferred coupling (i.e., where one element is coupled to another element by inference) includes direct and indirect coupling between two elements in the same manner as “operably coupled”. As one of average skill in the art will further appreciate, the term “compares favorably”, as may be used herein, indicates that a comparison between two or more elements, items, signals, etc., provides a desired relationship. For example, when the desired relationship is that signal 1 has a greater magnitude than signal 2, a favorable comparison may be achieved when the magnitude of signal 1 is greater than that of signal 2 or when the magnitude of signal 2 is less than that of signal 1.

The preceding discussion has presented a method and apparatus for detecting the presence of a valid signal while reducing the power consumption to do so and improving the receiver sensitivity. By avoiding continually adjusting the receiver sections gain prior to the reception of a valid signal, power consumption is reduced as well as receiver sensitivity is at least maintained. As one of average skill in the art will appreciate, other embodiments may be derived from the teachings of the present invention without deviating from the scope of the claims.